Economic and technical feasibility of replacing conventional combines with a new straw crusher combine

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Abstract: This study was conducted to investigate economic and technical feasibility of replacing conventional combines with a new combine harvester. In the new combine that called crusher combine, along with separating the wheat from the cluster and straw, the straw is also crushed and stored in a separate tank that is added to the combine behind the grain tank. Thirty conventional and new combine harvesters were randomly selected and examined. Parameters such as; combine forward speed, reel index, field capacity, pre harvest loss, head loss, threshing and cleaning loss, total loss and quality loss were measured. Results show that total machine loss in conventional and new combines were 3.93% and 4.44% respectively. However, in the conventional combines, all the grain loss are thrown to the ground but in new combine 2.45% of grains fall down in the ground through of platform and 2.46% of grains through of threshing and cleaning units are mixed with straw and collected in straw tank and is used to feed livestock. The amount of straw harvested by the conventional and new combines was 1570 and 2970 kg Ha^{-1} and yield was, 2770 and 2922 kg Ha^{-1}, respectively. Farmers are keen on the new combine because of gathering more straw, crushing it and storing it in the tank. The rate of seed breakage in seed tank of conventional and new combines were 3.37% and 2.81% and seed germination percentage were 90.8% and 94.7%, respectively. In new harvesters, due to the severe blows to the crushing unit, about 12.5% of the seeds have fracture or invisible damage and are unable to germinate, therefore, the grain harvested with this combine is not suitable for use as a seed. The results show that using the new combine instead of the conventional combine increases the income of the farmer and the combiner by 7 288 790 and 1 636 049 IRR Ha^{-1}, respectively.

Keywords: harvesting, loss, straw crushing combine, wheat

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1 Introduction

Wheat is one of the most important crops in Iran and its annual production is 14 million tons per year (Ahmadi et al., 2018). Wheat straw is a subsidiary or residual material that has been burned by farmers over the past decades. In recent years, due to climatic conditions in arid and semi-arid regions, water resources constraints, and shortage and cost of forage, the use of wheat straw as livestock feed has increased. In the 1980s, wheat straw harvesting was performing using forage harvesters and balers, but according to Rostami et al. (2019) report, the high cost of collecting wheat straw with this method has led to the idea of using combines able to chop and store straw in a reservoir during wheat harvesting. For this reason, new

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combines with the name of straw crushing combine have been introduced by applying changes to the conventional combines, which was evaluated in this paper.

Agheleshkhani (2017) examined two types of John Deere 955 combine including conventional and straw crushing combines by measuring natural losses, harvesting platform losses, combine end losses and seed breakage rate in the tank. Result showed that there was no significant difference between conventional and straw crushing combines for the natural and head grain losses at both 12% and 19% grain moisture content. However, there was significant difference between these two combines from the processing loss and seed breakage point of view so that combine processing loss and seed breakage in straw crushing combinewere much lower than those of the conventional combine. Rostami et al. (2018) compared harvesting losses rate of the John Deere 955 (Iran) and Class 76 conventional combines with John Deere 955 (Iran) and Class 76 straw crushing combines. The results showed that there was significant difference between the straw crushing and the conventional combines from the total harvesting losses point of view in both Class and John Deere models. The losses of John Deere straw crushing occurred mostly at the combine wheat storage tank with the value of 4.16%, whereas the losses in Class straw crushing combineoccurred mostly at the threshing and cleaning units which was about 8.13%. Rasheh et al. (2015) studied the effect of travel speed and combine head cutting height from land level in the fields with different grain yields on the grain loss of Kurdistan straw crushing combine (K130). Results showed that forward speed, cutting height and yield had significant effect on grain losses of all three studied parts (head, threshing and seprating units) at 1% level. The maximum total loss and threshing and cleaning losses were 3.8% and 2.7%, respectively at the forward speed of 2.5 km h^{-1}, field yield of 6500 kg ha^{-1}, and combine cutting height of 10 cm. The lowest amount of grain entered to the straw reservoir (0.56%) was at the travel speed of 1.5 km h^{-1}, yield of 3200 kg ha^{-1} and cutting height of 20 cm, and the lowest total combine loss was 0.76%.

Nahid and Karami (2010) in their research reported that the main reasons for the tendency of most farmers to burn plant residues are, short time interval for second planting, lack of extension recommendations and lack of proper plant for optimal control of plant residues. In order to solve this problem, programs such as changing the crop pattern, introducing new varieties with short growing periods, encouraging and punitive laws and providing farmers with appropriate technologies, has been suggested as a practical way to prevent residual fires and one of these methods is to use a straw crushing combinefor wheat harvesting. Mangaraj and Kulkarni (2005) studied wheat straw retrieval from combine harvested field for use as cattle feed. They came to the conclusion that, instead of burning of straw in the field, retrieval of straw by mechanized harvesting after grain combining could be a better option. The net income was estimated to be 1653 IRR HRa^{-1}.

Tang et al. (2017) designed and evaluated a multi-functional rice combine harvester that allows grain harvesting and straw baling. This multi-functional combine harvester could reduce the energy consumption required for rice harvesting and simplify the process of harvesting and baling. This multi-functional combine harvester could be used for stem crops (such as rice, wheat and soybean) grain harvesting and straw square baling, which could reduce labor cost and power consumption.

Although farmers are satisfied with the performance of straw crushing combineand their income has also increased due to the sale of wheat straw, the use of this combine has been conflicted in scientific circles. Therefore, the main objective of this study was to introduce straw crushing combines and to investigate some of the technical specifications, grain losses and economic evaluation of replacing conventional combines with new combines.

2 Material and methods

This research was carried out in wheat fields of Kerman, Fars and Hamedan provinces, Iran (Figure 1). In recent years, the number of straw crushing combines has been increasing in the country, especially in the abovementioned provinces. The new combine has been made by applying changes to the threshing cylinder and concave of conventional combines, add a straw tank and a vacuum fan and removing straw walker units (Figure 2). When harvesting wheat using straw crusher combine, wheat stem is harvested from near the ground level. The design of the threshing cylinder is such that it completely crushes the wheat straw and after the grain separation process, storing the crushed wheat straw in a tank.

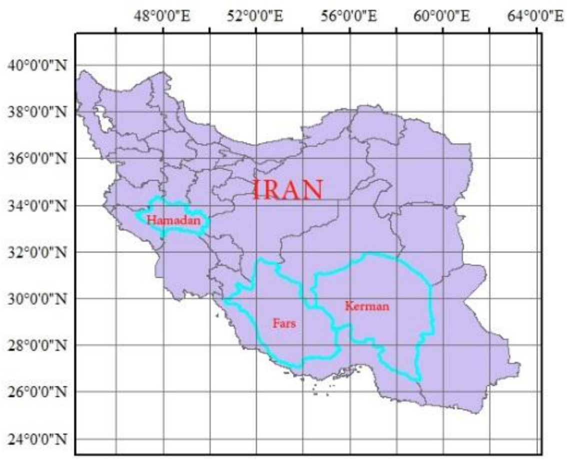


Figure 1 Provinces where tests are performed

Figure 2 Straw crusher combine harvester

The following changes should be made in the conventional combine to have a straw crushing combine:

Reducing the head (platform) width to reduce harvested material input rate;

Changing the threshing cylinder (Figure 3);

Changing the concave and replacing it with a perforated metal plate (Figure 3);

Removing the straw walker an adding a vacuum fan above sives;

Adding a new tank behind the grain tank to store chopped straw (Figure 4).

Figure 3 Threshing cylinder and concave in a new combine

Figure 4 Straw tank in new combine

In the new combine, wheat stem is crushed by the threshing cylinder while separating the grain from the cluster. The cylinder has blades that are rotating around a shaft. The concave in the new combine is a perforated metal plate with holes 20 to 30 mm in diameter. The concave is mounted under and slightly to the rear of the cylinder. The curvature of the concave generally conforms to the outer circumference of the cylinder. As the wheat crop enters the space between cylinder and concave the blades crush the straw in addition to separating the grain from the cluster by rotating the cylinder. Straw is crushed to the point where it can pass through the concave holes, so the whole crop including grain and straw goes through the concave holes and enters the cleaning unit. There is no straw walker similar to ordinary combine. The cleaning unit consisting of fan, sieve, grain tray, cleaned grain, residual auger and conveyor that are the same as in conventional combine units. Thers is a vacuum fan with a special design at the top of sieves to separate and transfer the crushed straw to the straw tank. The mixture of air and straw is sucked into the tank by this vacuum fan and the air comes out of an outlet window at the end of the tank. To prevent the outflow of fine straws and grains entering the tank with the straw, a 4 mm mesh screen is mounted to the tank top to separate the inlet channel from the outlet. A sensor is used in the tank to alert the driver when the tank is filled. The straw tank is dischaged before it is completely filled with straw. If the tank is completely filled with straw, the air outlet and the inlet of straw to the tank will be closed and the combine will be disrupted. Figures 5 and 6 show the flow chart and shematic of this combine harvester.

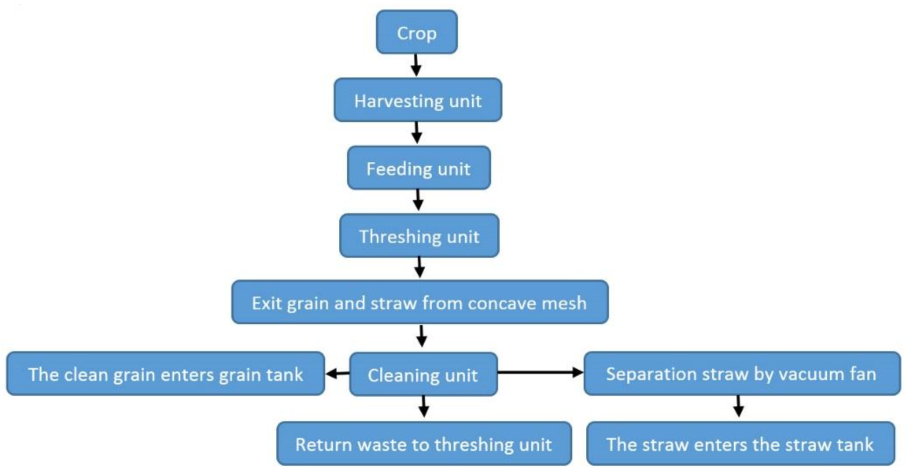
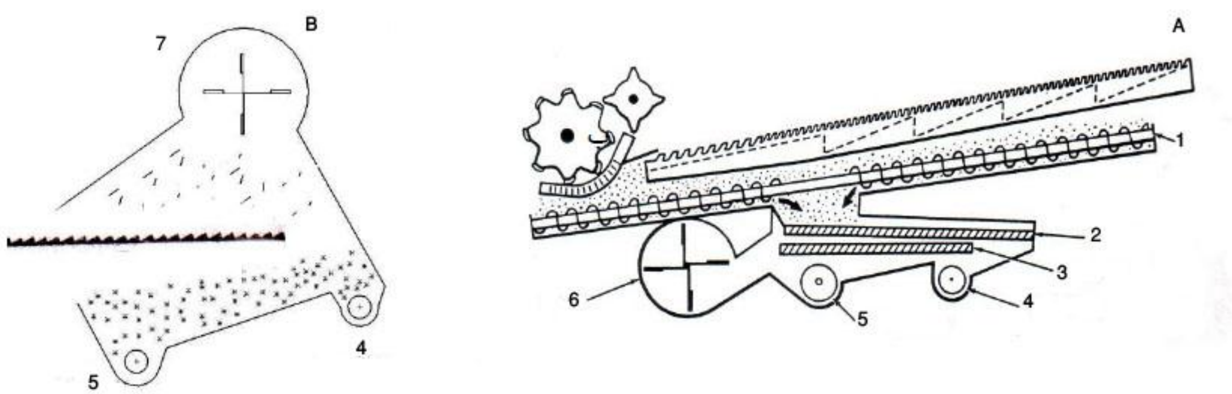


Figure 5 Flow chart of new combine harvester (Rostami et al., 2019)



Conventional (A) and new (B) combine (Safari et al., 2019)

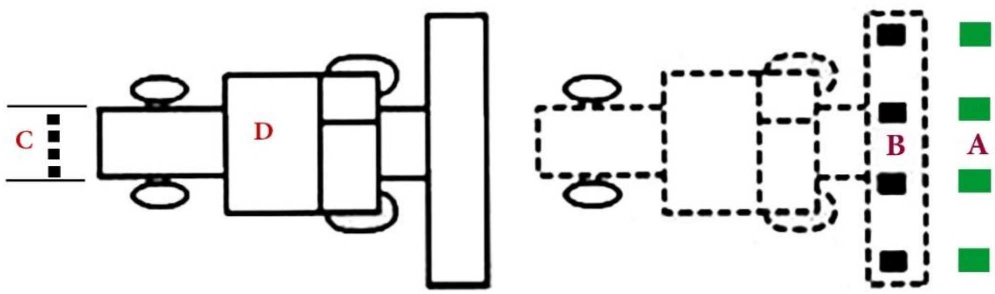
Figure 6 Schematic of cleaning unit

Note: 1- Grain auger; 2- Top sieve; 3- Bottom sieve; 4- Tailing auger; 5- Grain auger; 6- Fan; 7- Vacuum fan

Experimental combines were randomly selected in Kerman, Fars and Hamedan provinces. Ten conventional and new combine harvesters were examined in each province, a total 30 combines wer examined. To measure the linear combine reel speed, the time required for rotation of the reel was recorded in ten rounds. Given the number of rotations, the diameter of the reel and the timing, the linear speed of the reel was calculated. The reel index was calculated by dividing the reel linear velocity by combine forward speed. The combine forward speed was calculated by marking a distance of 50 m from the field and recording the time required to travel this distance by a stopwatch. The harvesting height of the combines was measured with a ruler. The field capacity of the combines was obtained by measuring the time needed to harvest each hectare of wheat in one working day. Useful platform width were measured during harvest.

Other information required was collected from combine drivers, farmers and experts and was recorded in forms like the; Combine prices, straw prices, straw harvested per hectare, combine age, information on oil replacements, filters, tires, combine drivers' fees, repair costs and other data needed to evaluate economically the use of new and conventional combines.

The parameters such as farm yield, pre harvest loss, head loss, threshing and cleaning loss, total loss and quality loss were measured for all combines. To measure farm yield, pre harvest and header loss, a wooden frame measuring 0.5×0.5 meters was randomly dropped at 6 points of field as shown in Figure 7 and grains that can be harvested with combine, grains and cluster shed prior to combine harvesting and grains and cluster shed after to combine harvesting in the wooden frame were collected and weighed separately, then the farm yield and the amount of loss was calculated in hectare.



Pre-harvest (A) and Header losses (B) in conventional and new combine harvesters, machine losses (C) in conventional and threshing loss (D) in new combine harvesters

Figure 7 Sampling places for estimating

There is no straw from the rear of the new combines and the straw is stored in the tank. The grain losses in the threshing and cleaning unit contains the grains that enter the straw tank with the straw. To measure the amount of these grains, the straw tank was first completely drained, then the combine moved 20 meters and harvested the wheat. The effective working width of combine was also recorded during harvesting. When harvesting was finished, the combine was stopped and a sack (3×3 meters) was placed at the rear of the combine and all collected materials in the tank were discharged on the sack (Figure 8).

Figure 8 Collection and transfer of straw in the straw combine tank for testing

Whole and broken grains were separated from the straw and weighted. The percentage of losses was calculated by taking the area harvested by combine and seed weight in hectare. To determine the quality loss of wheat, the percentage of broken grain in the grain tank and the germination rate were measured.

In order to assess the feasibility of replacing conventional combines with new combines, the cost and income of the combines were calculated from the farmers' and combiners' point of view. For farmers, the potential reduction in quantitative and qualitative waste was seen as a benefit and the increase in combine rentals was a cost. For the combiners, increase in rental income and the ability to harvest more wheat are considered to be benefits.

3 Results and discussion

The results of this study show that the amount of straw and grain harvested were 2770 and 2922 kg Ha^{-1} in the experimental fields for new combines and 1570 and 2970 kg Ha^{-1} for conventional combines, respectively. Therefore, the ratio of straw to grain harvested at the new combine was higher (0.95) than that of the conventional combines (0.53). Harvesting more straw and crushing the straw has made farmers prefer this new combine. The results showed that new combines harvest wheat stalks at a height of 14.8 cm above the ground, while conventional combines often drop two-thirds of the wheat stalks on the ground. Also, bailing the straw that falls from the back of the conventional combine to the floor will require a fee and the bailers will not be able to collect all the straw from the ground.

Table 1 Results of t-test for the studied traits

	t	df	Sig.	Mean Difference	Std. Error Difference
Head loss	3.387	28	.010	.82800	.24448
Threshing loss	.640	28	.540	.35400	.55327
Total loss	.933	28	.378	.50600	.54212
Germination	-3.374	28	.010	-3.86133	1.14436
Seed breakage	1.889	28	.096	.56400	.29854

Table 2 Mean, standard deviation and Std. Error Mean of studied traits

Factors	Combine type	Mean	Std. Deviation	Std. Error Mean
Head loss	New	2.45	.46248	**.20683**
	Conventional	1.63	.29146	**.13035**
Threshing loss	New	2.46	.89229	**.39904**
	Conventional	2.11	.85693	**.38323**
Total machine loss	New	4.44	1.02055	**.45640**
	Conventional	3.93	.65418	**.29256**
Germination	New	90.8	1.68217	**.75229**
	Conventional	94.7	1.92825	**.86234**
Seed breakage	New	3.37	.30325	**.13562**
	Conventional	2.81	.59470	**.26596**

The average platform width of the new combine investigated in this study was 384 cm, while the average width of the conventional combine platforms was 480 centimeters.

The forward speed of the new and conventional combines was 1.96 and 2.90 km h^{-1} respectively. Comparison of these two results shows that for optimum performance the new combines have to travel about 1 km slower than the conventional combines in the field, which

The results also show that combine drivers in dense fields did not even cover the entire platform width and used an average of 355 cm platform width in new combines, which reduced the combine's field capacity.

reduces their field capacity. The results also showed that the new combine harvesters had higher forward speeds in dryland (2.32 km h^{-1}) than irrigated fields (1.21 km h^{-1}), due to higher crop density.

The average annual yield of each combine harvester is estimated to be 1373 hours and the average field capacity of new and conventional combine harvesters was 0.42 and 0.91 Ha h^{-1}. According to the results, the field capacity of the new combines was less than half that of conventional combines. In general, the field capacity of new harvesters is underestimated for the following reasons:

1-Reduce the forward speed of the new combines compared to the conventional combines;

2-Lower platform width than conventional combines;

3-Time required to empty the straw tank;

These factors cause the field capacity of the new combine to be lower than that of the conventional combine, so harvesting wheat in one area's fields requires more combines.

The results of t-test for head loss, threshing loss, total loss, germination and seed breakage in both new and conventional combines are presented in Table 1 and Mean, Std. Deviation and Std. Error Mean are presented in Table 2.

According to the results of t-test (Table 1), it is seen that the changes in head losses are affected by the type of combine and had significant effect at the level of 1%. According to the results of Table 2, the average head losses in the crusher combine harvester was 2.45% and for the conventional combine, was registered 1.63. In threshing unit of new combine that acts like a thrasher machine, the entire input product is crushed by threshing cylinder blades. So that the threshing unit needs enough time to crush the crop and the fans and sieves need enough time to separate the grain from the straw (which is completely crushed). Therfore the combine dirvers, drive the combine with slower speed than conventional combine and as mentioned earlier the width of the combine head has also been reduced. One of the reasons for the higher grain loss in the head of new combines is that drivers drive new combines with lower speeds than ordinary combines while harvesting wheat (1.96 vs 2.90), but they do not reduce the speed of the reel. According to the basics of the combines, the linear speed of the reel should be 1.25 to 1.5 times higher than combine forward speed (Reel index= 1.25-1.5). As mentioned, the reel index of the new combines tested was 2.42. It was more than recommended, which causes a blow the reel into clusters and increases the losses.

According to the results of Table 1, the combine type has no effect on the threshing and total machine losses. It is important to note that the amount of losses in the threshing and cleaning unit of new combines are whole or broken grains that are mixed with straw and collected in the straw tank and are used by livestock during feeding process (Figure 9). These seeds were found as whole, semi-broken or completely crushed in straw. But grain losses in the threshing and cleaning unit of the conventional combine (end losses) are including the seeds that exit from the rear of combine and get out of reach.

Figure 9 Broken grains found in straw tank of new combine

If only the seeds that do not enter the grain tank are considered as grain losses, the new combine has a higher losses (4.44%) than conventional combine (3.93%), but if the losses be consist of seeds that fall on the ground, it will be 3.93% in the conventional combine and 2.45% in new combine. Due to the fact that the waste grain in the threshing and cleaning unit of new combine does not fall down on the ground and is mixed with straw and used as a feed for livestock, this new combine is preferable to conventional combine harvesting.

The seed breakage rate in the seed tank as well as seed germination rate are the qualitative parameters of the loss control in the combine. According to the results of Table 1, the grain fracture was not affected by the type of combine, but the percentage of seed germination in the new combine compared to the conventional combine has significantly decreased. It seems that the germination rate has dropped due to the impact on the wheat seedlings in the threshing unit.

Therefore, considering the total grain fracture and seed germination, the new combine should not be used for harvesting seed wheat, because about 12.5% of the seeds are broken or not able to germination. Grain breakage by new tested in this research was higher than what reported by Rahimi and Khosravani (2005) for conventional combine harvesters in Iran (2.01%). Germination of wheat seeds harvested with new combine in this research was less than what reported by Lashgari et al. (2007) for the conventional combines in Iran (96.6%). It seems that the germination rate has dropped due to the impact on the wheat seedlings in the threshing unit. Therefore, grain harvested with this combine is not suitable for use as a seed because about 12.5% of the seeds are broken or not able to germinate.

For conservation tillage in wheat residue, rows of residue after combine harvesting must be removed from the field, which requires time and expense for the farmers. But from behind the new combine, the straw does not spill and conservation tillage can be done immediately.

For economic comparison of conventional and new combines, fixed and variable costs and income were determined. The economic evaluation of the combines was then carried out using the partial budgeting method. The general specifications of the experimental combines and fields obtained in this study include, purchase price, field capacity, annual operating, field yields and straw are listed in Table 3.

Table 3 Estimation of wasted wheat value at harvesting in new and traditional combine

Combine type	Pourchase price IRR	Annual operation (hr)	Yield (Kg Ha^{-1})	Straw (Kg Ha^{-1})	Field capacity (Ha hr^{-1})
New combine	1 800 000 000	1373	2 922	2 770	0.42
Conventional combine	1 600 000 000	1373	2 970	1 570	0.91

Note: Reference: Research data

The total cost of fuel, oil (Motor, Hydraulic and etc.) and filters (oil, hydraulic, fuel, air) replacement, repair and service costs, tire costs, driver costs, and Transportation costs were calculated in one hour (Table 4). To calculate the fixed cost, the purchase price of the combine at a discount rate of 12 percent is converted to a uniform annual equivalent and divided by the year of operation of the combine (Table 4).The results showed that the variable cost of using conventional and new combines was 283 447 and 308 334 IRR hr^{-1}, respectively.

Table 4 Variable and fixed costs of using combines (IRR hr^{-1})

Combine type	Tyre cost	Maintenance, repair and service cost	Personnel cost	Fuel cost	Total variable cost	Fixed cost	Total cost
New combine	1 499	94 835	170 000	42 000	308 334	258 387	566 721
Conventional combine	3 421	75 026	170 000	35 000	283 447	178 000	461 447

Note: Reference: Research data

The difference in the benefits of each of the combines is due to the difference in grain loss and farm capacity. The benefits of reducing grain loss are for farmers and increasing farm capacity for combiners. The value of grain loss is the lost benefit of farmers. Reducing the grain loss is an income for farmers (Table 5).

Table 5 Estimation of wasted wheat value at harvesting in new and traditional combine

Combine type	Grain loss (%)	Yield (Kg Ha^{-1})	Grain loss (Kg Ha^{-1})	Grain loss value (IRR HRa^{-1})
New combine	4.91	2922	143.5	2 *439* 500
Conventional combine	2.84	2970	84.3	1 433 910

Reference: Research data

Qualitative grain loss are related to grain breakage in different combines. When selling wheat to the government, this type of waste is considered to be a useful drop and does not affect the basic price of wheat up to 4%. The direct and indirect costs of farmers and combiners and their incomes are presented in Tables 6 and 7.

Table 6 Farmers' income and cost (IRR HRa^{-1})

Cost/Income type	**Description of cost and income**	**Amount (IRR HRa^{-1})**	
		New combine	**Conventional combine**
Direct costs	Combine rental fee	4 500 000	**2 000 000**
Indirect costs	Grain loss	2 439 500	**1 433 910**
	Straw bailing	0	**3 000 000**
	Transportation of straw	2 000 000	**2 000 000**
	straw sack	1 500 000	**0**
Direct gross income	Product Sales	49 674 000	**50 490 000**
Indirect gross income	Straw sales	12 049 500	**5 950 300**
Total direct and indirect costs		10 439 500	**8 433 910**
Total direct and indirect income		61 723 500	**56 440 300**
Total Farmer's net income		72 1630 00	**64 874 210**
Difference in income of two combines		7 288 790	

Table 7 Combiners' income and cost (IRR HRa^{-1})

Cost/Income type	Description of cost and income	**Amount (IRR HRa^{-1})**	
		New combine	**Conventional combine**
Direct costs	Fixed cost	615 207	**195 604**
	Variable cost	734 128	**311 480**
Indirect costs	Capital depreciation	40 500	**28 800**
	Insurance	30 000	**20 000**
Direct gross income	Combine rental	4 500 000	**2 000 000**
Total direct and indirect costs		1 419 835	**555 884**
Total direct and indirect income		4 500 000	**2 000 000**
Total combiner's net income		3 080 165	**1 444 116**
Difference in income of two combines		1 636 049	

The results of Tables 6 and 7 show that using the new combine instead of the conventional combine increases the income of the farmers and the combiners by 7 288 790 and 1 636 049 IRR Hra^{-1}, respectively. This increase in revenue is due to the higher quality and quantity of straw and its sale at a higher price and lower costs associated with baling and straw harvesting. According to these results, replacing conventional combines with new combines is justifiable financially for farmers and combiners.

In conclusion, results indicated that totla machine grain loss in new and conventional combine had not significant difference. The amount of straw harvested by the new combines per hectare was 1.76 times more than the conventional combine harvesters, therfore farmers prefer to use new combine harvester to harvest wheat due to increased income from straw. Combiners also prefer to use the new combine because of its higher revenue, but because of its lower field capacity than the conventional combine, more combines should be used in the country whose economic viability should be carefully evaluated.

4 Conclusion

In conclusion, results indicated that total machine grain loss in new and conventional combine had not significant difference. The amount of straw harvested by the new combines per hectare was 1.76 times more than the conventional combine harvesters, therfore farmers prefer to use new combine harvester to harvest wheat due to increased income from straw. Combiners also prefer to use the new combine because of its higher revenue, but because of its lower field capacity than the conventional combine, more combines should be used in the country whose economic viability should be carefully evaluated.

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